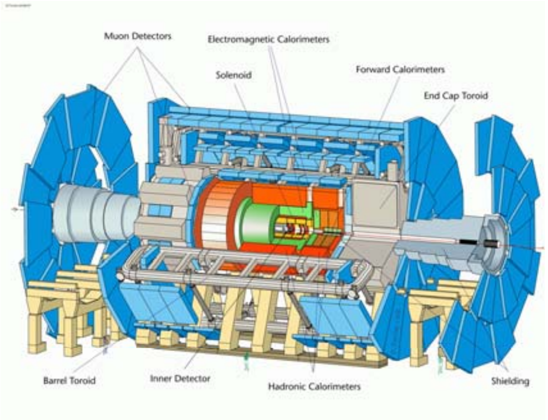
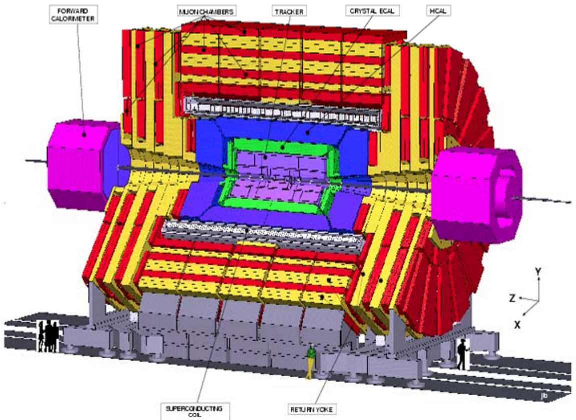
Physics at LHC-2008

Split-CROATIA,
29.9. – 4.10.2008



B-physics with ATLAS and CMS



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representing
ATLAS / CMS collaborations

B-physics @ ATLAS/CMS

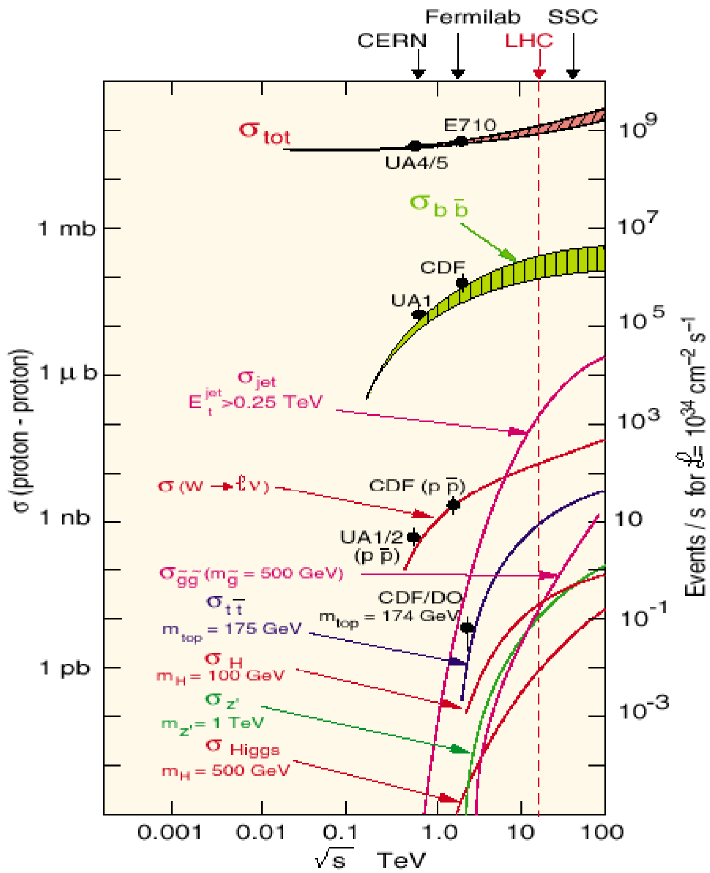
- p-p collisions at $\sqrt{s}$ = 14 TeV: σ (bb) = 500 μb

  10^5 bb pairs /s @ L=10^{33} $cm^{-2}s^{-1}$
  huge statistics allows precision measurements of B hadron species

- LHC ratio $\sigma_{bb}/\sigma_{inel}$ is higher compared to earlier accelerators –> μ rate from B-events is higher

- ATLAS / CMS are general purpose detectors, however B-physics requirements were taken into account in detector and trigger building

- robust muon and di-muon triggers –> possibility to collect valuable B-physics events with LHC data



B-physics program @ATLAS/CMS

Early data period:

- L_{int} = 10 – 100 pb^{-1}:
  - early measurements from J/Ψ and ϒ and b-quark cross-section, QCD tests at new energy
  - large b cross-section will allow early extraction of exclusive decays, like $B^+ \rightarrow J/\Psi\ K^+$, $B_d^0 \rightarrow J/\Psi\ K^{O*}$, $B_s \rightarrow J/\Psi\ \Phi$
  - J/Ψ, ϒ and exclusive B-channels will be a tester for detector calibration (mass, lifetime, etc)

- L_{int} = 200 pb^{-1} – 1 fb^{-1}:
  - high statistics will allow to improve worlds precision of lifetime measurements
  - set new limit for $B_s \rightarrow \mu\mu$
  - improve measurement on B_c and Λ_b

B-physics program @ATLAS/CMS (cont)

Main data period: L_{int} = 10 – 30 fb^{-1} and higher

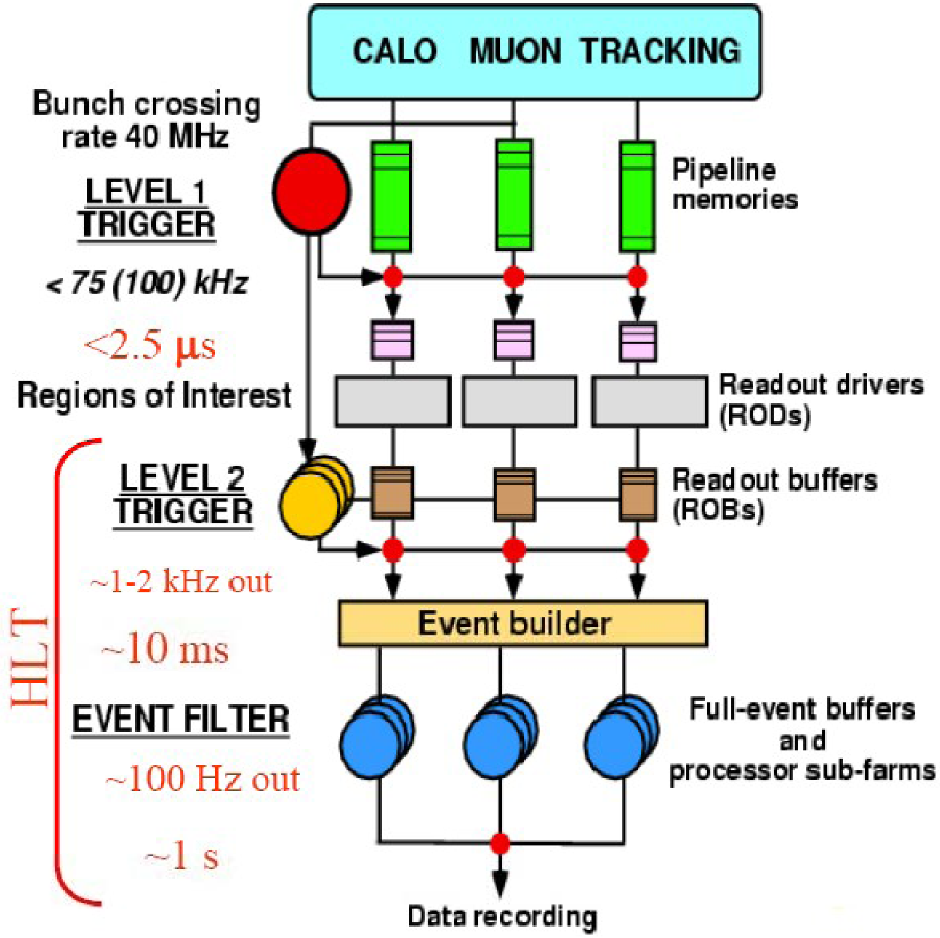
- rare and semi-rare decays: $B_s \to \mu\mu$, $b \to d,s\ \mu\mu$
- CP-violating B_s mixing phase studies: $B_s \to J/\Psi\ \Phi$, $B_s \to D_s\pi(a_1)$
- Λ_b polarisation: $\Lambda_b \to \Lambda\ J/\Psi$
- full potential of B_c and other heavy flavour hadrons
- lepton flavour violating search: $\tau^- \to \mu^-\mu^+\mu^-$

covers a wide range over the different LHC periods for
SM and New Physics (NP) measurements

Trigger strategy in ATLAS

ATLAS trigger schema

- <u>LVL1</u>
  - hardware-based, identifies Regions of Interest (RoI) for further processing
- <u>LVL2</u>
  - confirm LVL1 trigger
  - precision muon chamber and inner detector measurements in LVL1 RoI
- <u>EF</u>
  - refine LVL2 selection using offline-like algorithms
  - full event, alignment and calibration data available



Three level Trigger:
L1 → hardware
HLT (L2+EF) → software

B-physics Trigger in ATLAS

B-Physics is accounted for 5÷10% of total trigger resources:

it must be fast, efficient and selective

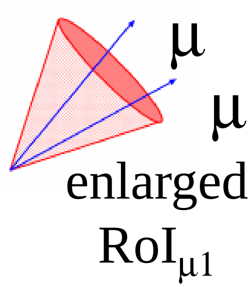
At L = 10^{33} cm^{-2} s^{-1}: (low luminosity)

L1: B-trigger is based on following strategies:

di-muon L1 signature or single muon combined with Jet- or EM-RoI

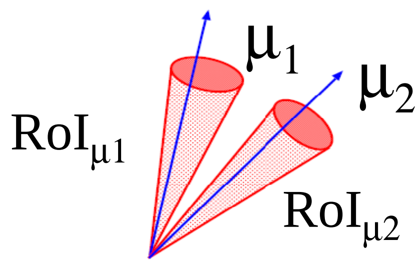
L2:

- topological di-muon trigger (see high luminosity)
- if only one L1 muon → the second muon is found at the HLT stage
- hadron trigger: tracking in the ID to reconstruct hadrons in RoI, specific for each channel, e.g. $D_s(\Phi\pi)$, rare semi-leptonic channels



At L = 10^{34} cm^{-2} s^{-1}: (high luminosity)

- topological di-muon trigger:
  based on two L1 muons confirmed at L2
- optional increase of pt-threshold

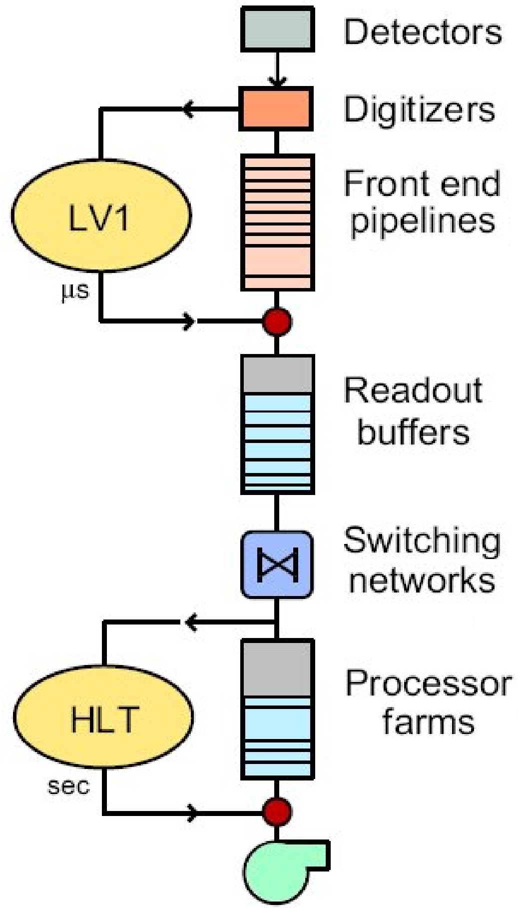


Trigger strategy in CMS

Two Level Trigger: L1 → hardware
HLT → software

- Level 1 Trigger (L1) - hardware
  based on muon detectors and calorimeters
  processing time: 3.2 μs
  40 MHz → 100 kHz

- High Level Trigger (HLT)
  fast (local) reconstruction similar to offline analysis
  has access to all event data with full precision and granularity
  processing time: ~1s
  100 kHz → 150 Hz

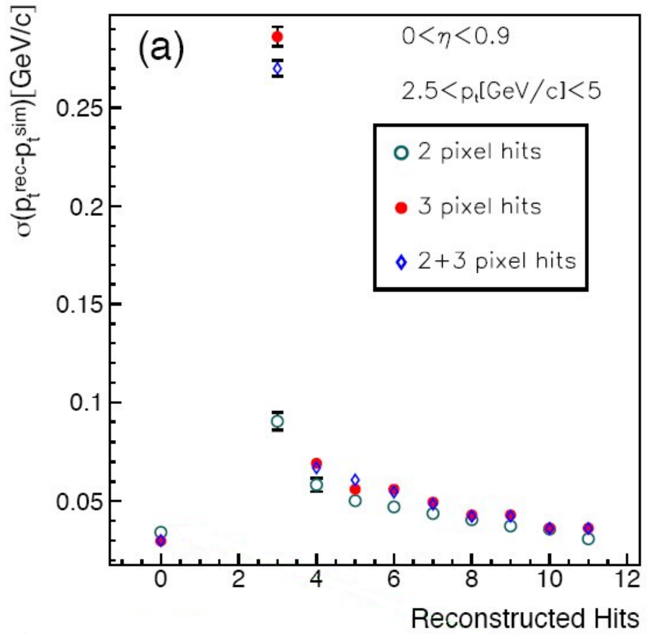


B-physics Trigger in CMS

At L1:
Single muon: p_T > 7 GeV/c (14 GeV/c for L_{high})
Di- muon: p_T > 3 GeV/c (7 GeV/c for L_{high})

At HLT:
Exclusive and inclusive B triggers ~ 5Hz

- reconstruction of three most possible vertices with pixel detector
- regional track reconstruction around L1 μ
- search for (un)like charge track pairs in given mass window
- partial reconstruction combined with p_T-cuts

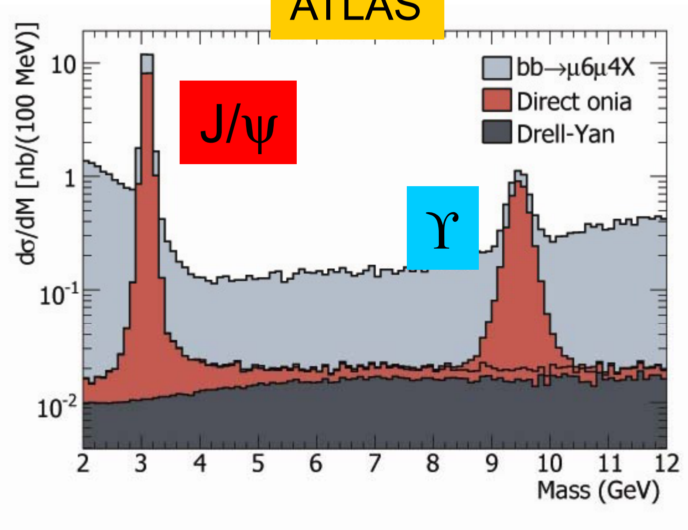


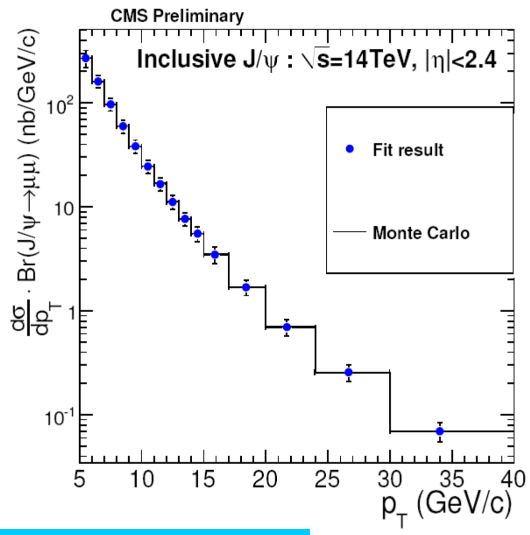
Quarkonia: production

J/ψ –>di-muon
main channel for early data
clear signature –>
calibration, event monitoring

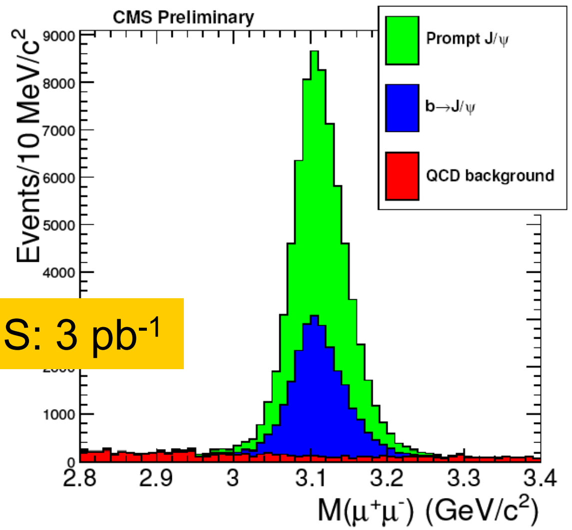
Already with first LHC data enough statistics to probe different production models

ATLAS





Inclusive J/ψ cross-section

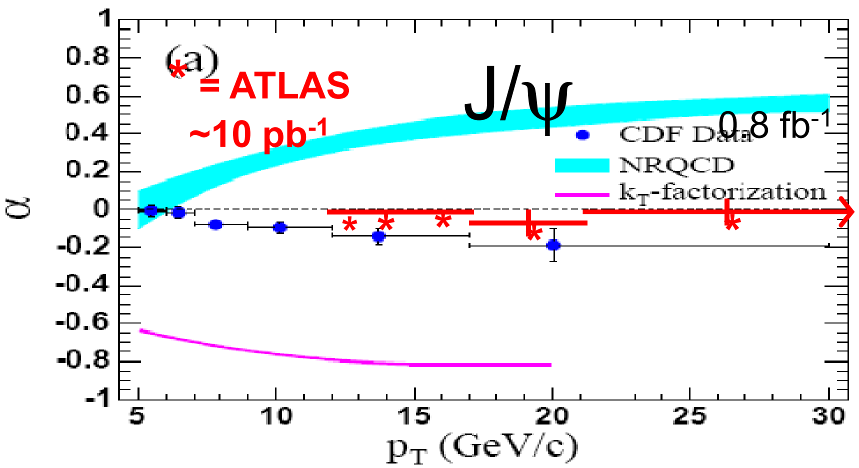


CMS: 3 pb^{-1}

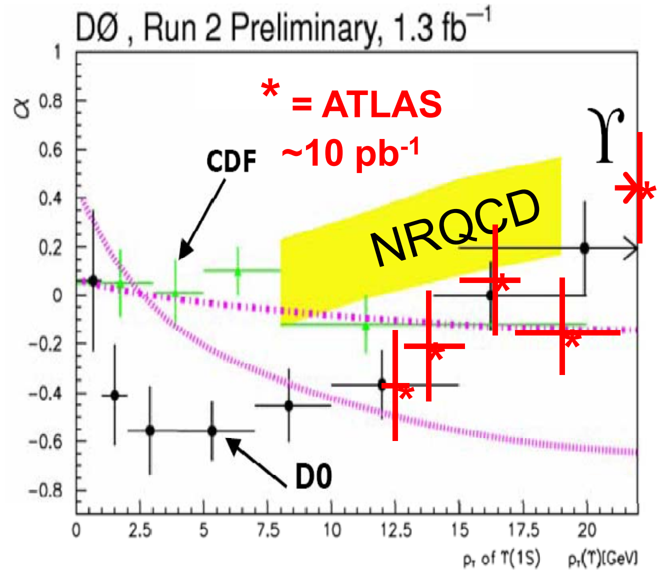
Quarkonia: polarization

Production mechanism of quarkonium unexplained and polarization for J/ψ and ϒ not understood (α .. polarization parameter)

CDF and DØ measurements on J/ψ and ϒ are not in agreement with each other and theoretical predictions



Crude superimpose of ATLAS stat uncertainties with 10 pb-1 assuming α=0 :



Already with 10 pb^{-1} ATLAS will measure J/ψ polarization to same precision as Tevatron with 1.3 fb^{-1} - but with interesting high p_T data!
Same precision for ϒ polarization studies can be reached after ~100 pb^{-1}

Weak phase of B_s mixing

The weak phase of Bs mixing, ϕ_s is very small and precisely predicted within SM

$\phi_s^{SM} = -\arg(V_{ts}^2) = -2\lambda 2\eta = -0.0368 \pm 0.0018$

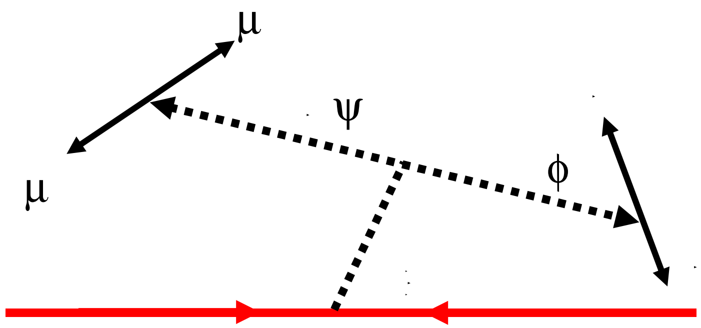
some NP- models predict large ϕ_s

CDF and D0 set confidence level bounds on
$\Delta\Gamma_s$ - ϕ_s
Their conclusion:

- assuming SM values $\Delta\Gamma_s = 0.096\ ps^{-1}$ and $\phi_s = 0.04$ the probability of deviation of these values of as large as the observed data is 15 % (CDF) and 6.6% (D0)

experimentally most feasible channel is

$B_s \to J/\Psi(\mu\mu)\ \Phi(KK)$:



Measurement of ϕ_s is challenging
$\to$ could point to NP

CPV with $B_s \to J/\Psi\ \Phi$ (ATLAS/CMS)

$B_s \to J/\Psi(\mu\mu)\ \Phi(KK)$:

- good to trigger ($\mu\mu$)
- good BG suppression
- Experimental information:
  3 angles, proper time, flavor tag,
  BG–fraction + composition
  Δm_s measurement from $B_s \to D_s\pi(a_1)$
- Independent information of uncertainties of experimental values
- huge statistics (~100k per year) → multivariable analysis with
  5 parameters + constraint input values

ATLAS, CMS after 30 fb^{-1}
→ $\delta(\phi_s) = 0.07$ each
(larger through NP?)

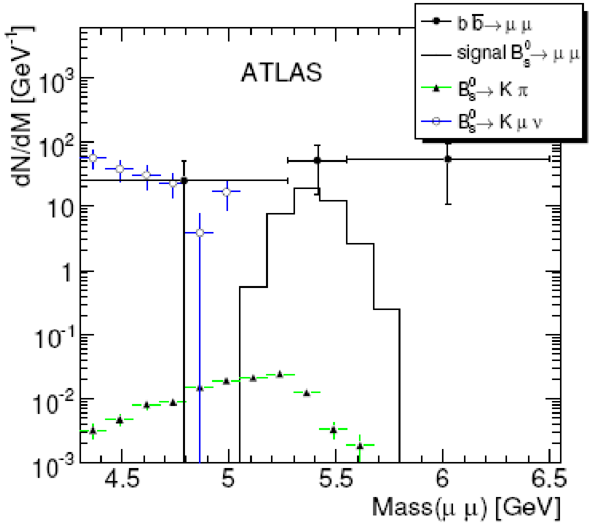
	ATLAS	CMS
Luminosity	**30 fb^{-1} / 3Y**	
Statistics	240000	260000
Background	30%	33%
	dominant B_d-J/y, K* B_d-J/y $K^+\pi^-$	
Time resol	83 fs	77 fs
Mass resol	16.6 MeV	14 MeV
Flav tagging	μ, e, Qjet	μ, e, Qjet
ϕ_s	0.067	0.068
$\Delta\Gamma s$	13%	12%
Γs	1%	0.9%
$A_\parallel$	0.9%	0.8%
$A_\perp$	3%	2.7%
Δm_s (ps^{-1})	17.77 +- 0.12	
$\delta_1\delta_2$	Fixed from B_d-J/y K*	

$B_s \rightarrow \mu\mu$

NP may enhance the BR $(3.42 \pm 0.46) \cdot 10^{-9}$ in SM by several orders of magnitude through new loop diagrams

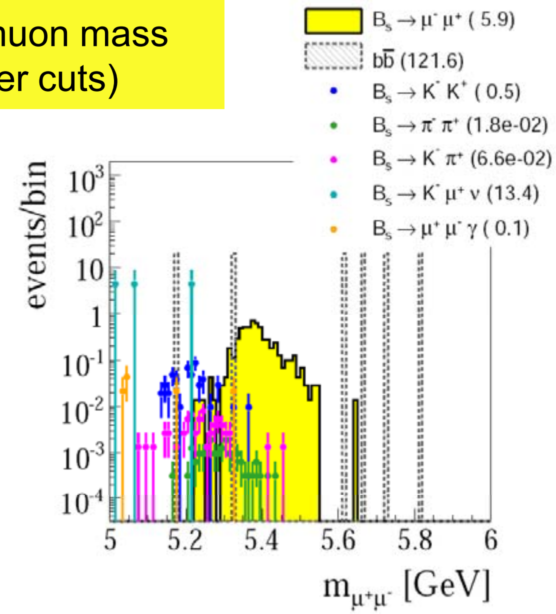
present best limit: CDF (2007) with 2 fb^{-1} of data

$BR(B^0_s \rightarrow \mu^+\mu^-) < 5.8 \cdot 10^{-8}$ at 95% CL $(=17 \cdot Br_{SM})$



- trigger is di-muon signature → search also at nominal LHC L $=10^{34}$ $cm^{-2}s^{-1}$
- main issue of cuts is background rejection (comb bb→ $\mu\mu X$, hadron misidentification, rare B-decays)

Dimuon mass (after cuts)



ATLAS / CMS have similar discriminating variables with different selection cut values:

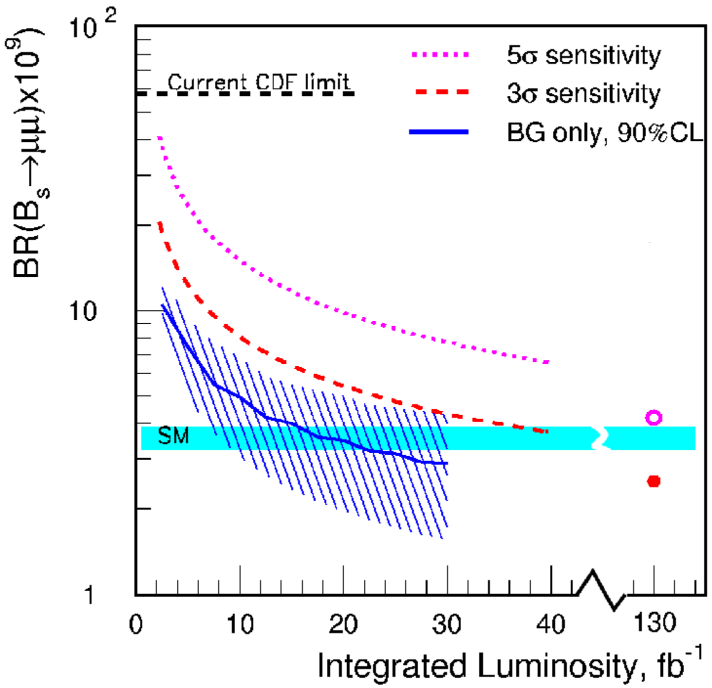
✓ isolation of the muon pair
✓ significance of the decay length
✓ angle between di-muon momentum and direction to PV
✓ mass window around $m(B_s)$

More details for CMS:
see talk in the afternoon B.Caponeri

$B_s \to \mu\mu$: results

For 10 fb^{-1} signal and main backgrounds → expected number of events

	$B_s \to \mu\mu$	$bb \to \mu\mu X$	$B_s \to K\pi$	$B_s \to K\mu\nu$
ATLAS	5.7	14(+13,-10)	0.015	negl.
CMS	6.1	14(+22,-14)	< 0.3	negl.



$B_s \to \mu\mu$ sensitivity

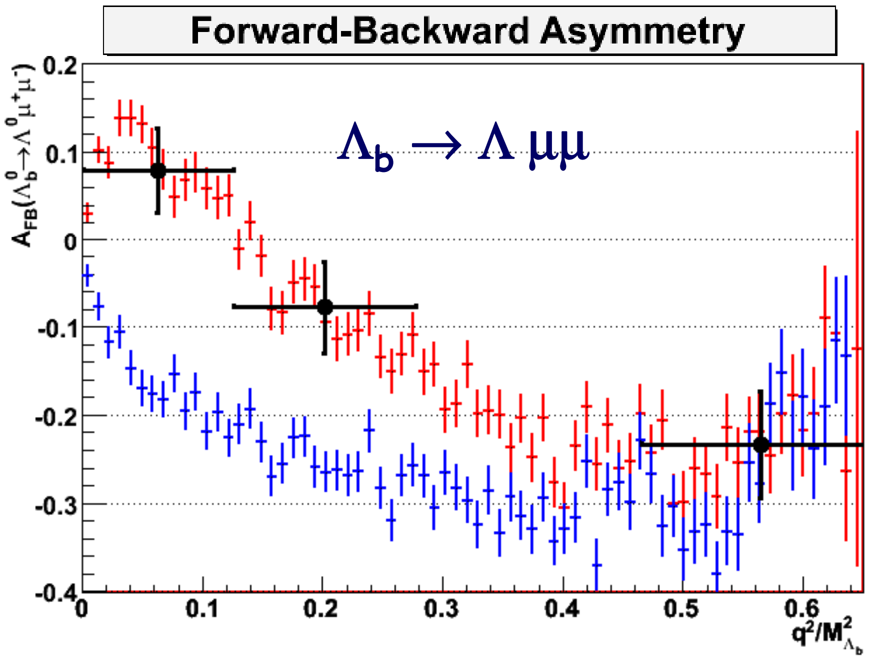
- with 2 fb^{-1} BR< ~ 2×10^{-8}
- with 10 – 20 fb^{-1} SM prediction region
- 3σ evidence after 3 years@10^{33}
- 5σ observation after 1 years@10^{34}

(signal cross section is translated to a BR by the reference process B+ → J/Ψ K+)

Exclusive semi-leptonic rare decays b→d,s μμ

b→s(d) $l^+ l^-$ FCNC transitions provide a good test of the SM and indirect search for signals in NP:

- CKM matrix
- differential decay rate sensitive to NP – A_{FB}, dilepton mass spectrum
- information on long-distance QCD effects



EXP, SM
MSSM C7geff>0

Exclusive semi-leptonic rare decays - trigger

L1 di-muon triggers :
study on different trigger cuts

HLT trigger:
specific for each channel
track search for charged hadrons from Φ, Λ_o, K_o^* decays in the RoI of ID surrounding the found di-muon signal

With 30 fb^{-1} ATLAS will achieve a sensitivity to distinguish between SM and certain classes of NP - models.

ATLAS supports semi-rare decays of all B-hadrons: B^+,B_0, B_s , Λ_b

30 fb^{-1} (3 years)	# of signal events
B $\rightarrow$ **K**^{0*} $\mu\mu$	2500
B$_s$ $\rightarrow$ ϕ $\mu\mu$	900
B$^+$ $\rightarrow$ **K**$^{+*}$ $\mu\mu$	4000
B$^+$ $\rightarrow$ **K**$^+$ $\mu\mu$	2300
$\Lambda_b \rightarrow \Lambda\ \mu\mu$	800

CMS has equivalent potential –
studies are on-going!

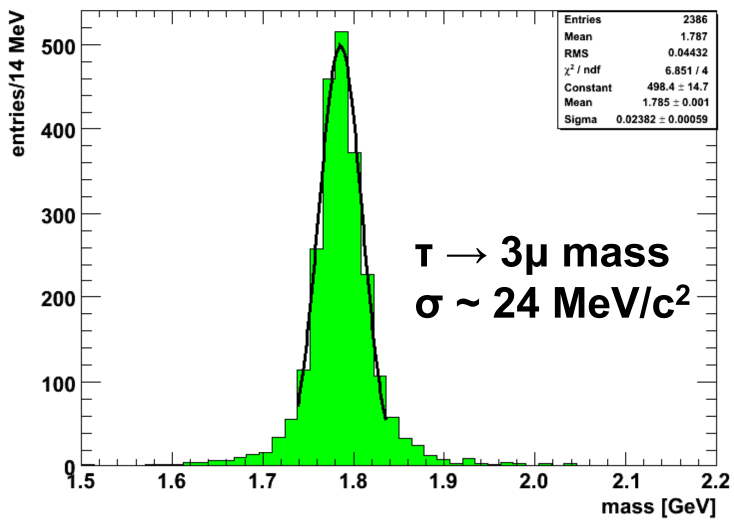
LFV in $\tau^- \rightarrow 3\mu$ (CMS)

SM lepton flavor violation is negligible, but some NP models allow BR ~ $O(10^{-10} \div 10^{-7})$

Current exp. limits:

BELLE BR $\leq 3.2 \times 10^{-8}$ (535 fb^{-1})

BaBar BR $\leq 5.3 \times 10^{-8}$ (376 fb^{-1})



τ sources at LHC –

- clean experimental signature
- suitable triggers

Decay	**N_τ / 10 fb^{-1}**
$W \rightarrow \tau \nu_\tau$	1.7×10^{8}
$Z \rightarrow \tau \tau$	3.2×10^{7}
$B^0 \rightarrow \tau X$	4.0×10^{11}
$B^\pm \rightarrow \tau X$	3.8×10^{11}
$B_s \rightarrow \tau X$	7.9×10^{10}
$D_s \rightarrow \tau X$	1.5×10^{12}

CMS L1: single $\mu \rightarrow p_T > 14$ GeV

di- $\mu \rightarrow p_T > 3$ GeV

CMS HLT: single $\mu \rightarrow p_T > 19$ GeV

di- $\mu \rightarrow p_T > 7$ GeV

At L_{high} more stringent trigger (pileup)

Summary

- ATLAS, CMS B-physics program is prepared for all LHC luminosities
- Early period ($<10^{33}$): heavy flavour production measurements provide good ground for QCD tests at the new energy
- 10^{33} period:
  - improve current world's precisions on properties of B-hadron species
  - reach sensitivity to New Physics effects in B_s CP-violation and in semi-rare B-decays
  - reach three sigma effect in $B_s \rightarrow \mu\mu$ (supposing SM)
- Nominal LHC luminosity (10^{34}):
  - thanks to powerful muon triggers ATLAS, CMS will reach $B_s \rightarrow \mu\mu$ five sigma sensitivity already after one year of running
- ATLAS, CMS B-physics data are a valuable source for SM and New Physics constraints

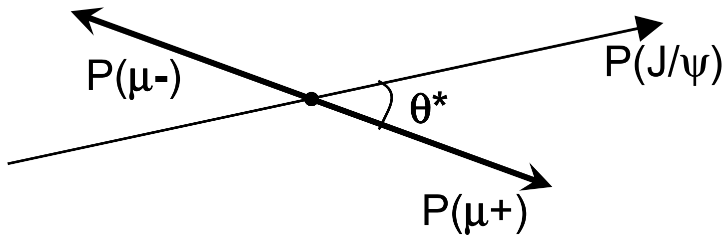
Backup

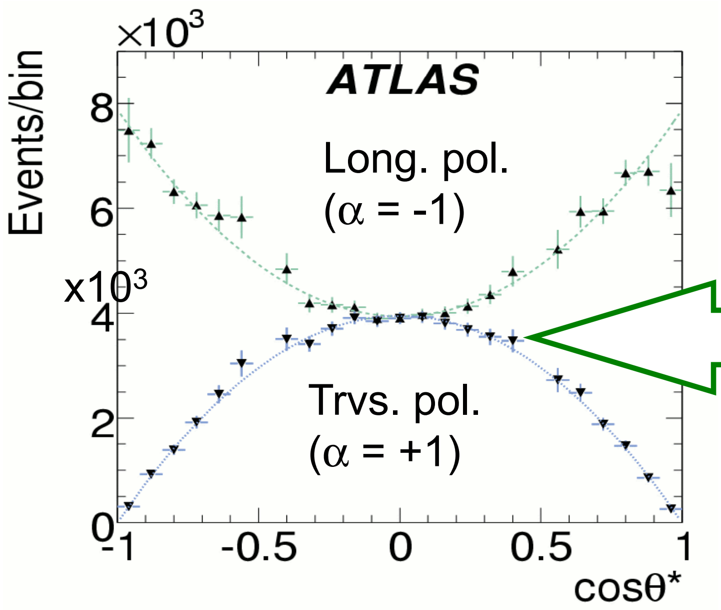
Backup

Polarization - Quarkonia

Measure high-p_T polarization to distinguish production models

$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha\cos^2\theta^*$$





Combine and fit to measured distribution in slices of p_T
Shown: $12 \leq p_T \leq 13$ GeV

Calculation of the 95% CL upper limit on the BR of $B_s \to \mu^+\mu^-$

- Use software that is also used by CDF
  http://www-cdf.fnal.gov/physics/statistics/statistics_software.html
  - Bayesian method
  - blimit.C returns s_{up} such that $\int_0^{s_{up}} p(s|N_{obs})ds = \beta$
    - s ... signal rate
    - $p(s|N_{obs})$ ... posterior p.d.f. for s, given N_{obs}
    - s_{up} = blimit$(\beta, N_{obs}, \varepsilon, \Delta\varepsilon, N_{bg}, \Delta N_{bg}, \alpha)$

      β ... CL value (0.9, 0.95)

      $s^{(\alpha-1)}$ is the prior p.d.f. for the signal s

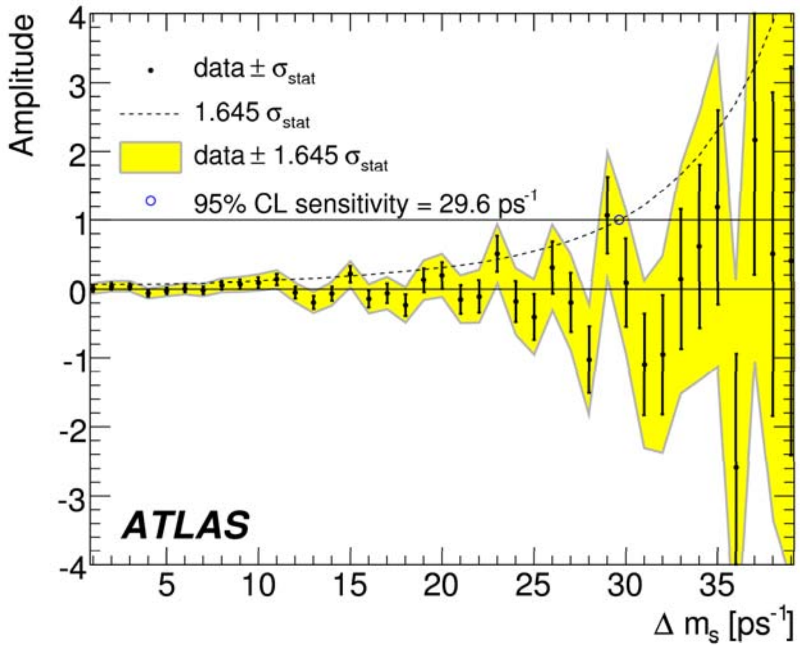
      $N_{obs} = \varepsilon \cdot s + N_{bg}$, ε = signal efficiency
  - N_{bg} very large uncertainty due to limited MC statistics
    - will be estimated from sidebands, once data are available
  - Setting $N_{obs} = N_{bg} \pm \Delta N_{bg}$ one gets the upper limit s_{up} on the signal cross section in the absence of signal
    - see blue curve and hatched region on slide 14

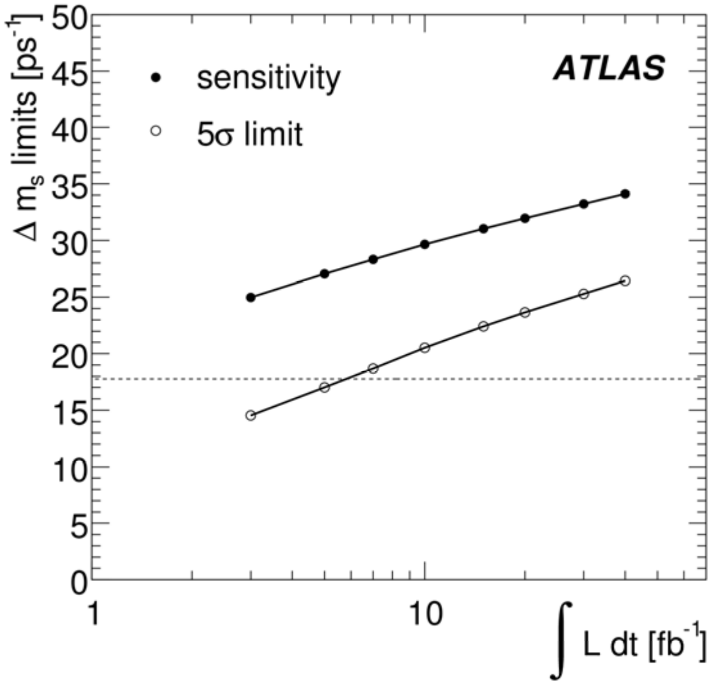
Calculating the 3(5)σ discovery sensitivity

- If $(N_{obs} - N_{bg}) / \sqrt{N_{bg}} >> 1 \rightarrow$ evident discovery
  - this quantifies the significance of a discovery

- Therefore use the following simple relation
  - $N_{signal} = (N_{\mathbf{obs}} - N_{\mathbf{bg}}) = \; 3 \cdot \sqrt{N_{bg}}$ and $5 \cdot \sqrt{N_{bg}}$
    - $N_{bg} \propto L_{int}$
    - $N_{signal} = \varepsilon \cdot \sigma(B_S) \cdot Br(B_S \rightarrow \mu\mu) \cdot L_{int}$
  - $Br(B_S \rightarrow \mu\mu)$ for xσ discovery sensitivity scales with $\sqrt{L_{int}}$

Sensitivity for a Δm_s measurement





B_s^0 oscillation amplitude as a function of Δm_s for 10 fb^{-1} using the amplitude fit method

fully hadronic decay channels $B_s^0 \rightarrow D_s^- \pi^+$ and $B_s^0 \rightarrow D_s^- a_1^+$ combined

- 95% CL sensitivity: 29.6 ps^{-1}
- 5 σ measurement limit: 20.5 ps^{-1}